Ground-Based Optical Leak Detection

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Leak checks on liquid-propellant rocket engines are labor- and time-intensive and rely upon technician judgment. Ground-based optical leak detection was developed to accelerate and automate the leak detection and location process in response to demands for shorter turnaround times, reduced life-cycle costs, and enhanced mission confidence. It is a remote, near-real-time, computer-based, passive optical infrared imaging method that utilizes differential absorption of the nitrous oxide tracer gas. Providing sensitive leak detection and location, the system eliminates inconsistent technician evaluations and reduces leak inspection cycle time from 3 days to just a few hours. A portable optical leak detection system has been developed and successfully used in laboratory, shop floor, outdoor, and test stand environments.

Space shuttle main engine leak inspections include a subjective, time-consuming, manual soap-solution test of over 140 joints. An extension of this technique to all joints, welds, and brazes on the engine would be prohibitively difficult and expensive. However, approximate leak rates for the leak locations of these 140 joints are known. Helium bag leak checks are very sensitive, but the location of the leak cannot be determined except by performing subsequent soap-solution inspection. The present leak testing process (soap and bagging) takes roughly 3 days for flight applications, contributing to the turnaround duration of the orbiter.

The Rocketdyne Division of Rockwell International Corporation is developing optical leak detection to reduce leak inspection time and increase mission confidence by rendering leaks within the field of view of an infrared focal plane array video camera instantly visible to the inspector via a television or computer monitor. The engine is pressurized with nitrous oxide, which strongly absorbs infrared radiation. Use on the space shuttle main engine was approved after an extensive compatibility study. The leaking gas is imaged with a filtered infrared camera, and the leaking gas absorbs the incident ambient or lamp infrared radiation, appearing as a dark billowing cloud on the television monitor. Unfortunately, if the leak is small, the dark cloud may be impossible for the human eye to discern.

To automate the process and make small leaks visible to the human eye, camera images are digitally processed. The resulting image of the leaking gas is highlighted in white and superimposed over an initial image, clearly showing the location and extent of the detected leak. Overlaid images are displayed four times per second.

The portable system, designed and assembled by Rocketdyne, consists of a 128- by 128-array InSta™ infrared camera on a wheeled tripod and a wheeled console containing a computer hosting an image processor, monitor, television monitor, video cassette recorder, and the camera electronics. The console can also be lifted by crane or hoist.

Laboratory and shop floor testing with simulated leaks of 0.25 standard cubic inches per minute was successful. Due to cool air-conditioned temperatures, use of a heat lamp or studio-type quartz lamp enhanced the sensitivity of the system. Wind tests, up to 900 feet per minute, were conducted. Results at velocities up to 100 feet per minute were strikingly good. At flow rates above 100 feet per minute, the leak became gradually more obscured due to gas flow away from the leak location and cooling effects. Outdoor sunlight tests were also very successful despite wind gusts that caused cooling effects.

Final testing was performed on the oxidizer side of the space shuttle main engine in the NASA/MSFC Technology Test-Bed test stand. The engine was filled with nitrous oxide through the helium pressurization line. During the first test, with winds gusting between 8 and 15 miles per hour, no leaks were detected. The test stand engineer verified that there were no leaks (no false positives). The test time was only 2 hours, including rechecking, adjustments for the extreme wind conditions, and waiting for gas-bottle exchange. Testing indicated that, with little practice, the entire engine could be done in only slightly more time.

Despite the high gusting winds, a known fuzz leak was detected easily. The leak was shown to be visible well below soap-solution detectability limits. An undisclosed leak was then created and easily detected. The leak was quickly determined to be in a 4-inch cube volume in the space between and behind the high-pressure oxidizer turbopump and the pogo system hardware. Detectability was measured at class 3, class 1, and fuzz-leak levels with excellent results. By moving the camera around the engine, the leak source was triangulated. At the appropriate viewing angle, the leak was detected as coming from a sensor port on the backside of the duct that carries liquid oxygen from the oxidizer turbopump to the fuel preburner in a location hidden by the ducts running between the turbopump and the pogo system. With the majority of joints, direct visual access is possible. To completely locate all leaks, it will be necessary to move the camera around the engine or place multiple cameras in strategic locations around the engine.

A new portable system that uses a staring focal-plane-array infrared detector has been developed. This system can detect leaks with ambient illumination, rather than the laser illumination required for its predecessor. Ground-based optical leak detection has successfully demonstrated a unique capability for detecting and locating small leaks (level 1, fuzz, and smaller) remotely and rapidly (4-Hz frame rate) in the laboratory, shop floor, outdoor environments, and on an engine test stand, showing great promise as an important future tool in rapid, reliable, and remote engine inspection under a variety of conditions. Benefits of using the optical leak detection system include a significant increase in sensitivity and repeatability over soap leak inspection and a significant reduction in the time required to perform leak checks.

Maram, J.; Wyett, L.M.; Delcher, R.C.; and Reinert, J.W. Optical Methods for Remote Rocket Engine Condition Monitoring. Proceedings of the 1988 Conference on Advanced Earth-to-Orbit Propulsion.

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